7 Soil Quality

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7.1 Introduction

The Welsh Government has commissioned the comprehensive Glastir Monitoring and Evaluation Programme (GMEP) to monitor the effects of Glastir, its new land management scheme, following on from former schemes such as Tir Cynnal, Tir Gofal and the Organic Farming Scheme. The monitoring contributes towards reporting on a range of international biodiversity and environmental targets. The data, models and tools collected and developed within GMEP will also help inform future planning of Wales' natural resources in a joined-up way to ensure the development of a green economy and the aspirations of the Environment Bill. Healthy soils produce our food, feed and fibre, whilst providing other important functions such as regulating climate and water and attenuating pollutants. They are a biodiverse ecosystem in themselves needing to be fed and watered, and contain an estimated quarter of global biodiversity, whilst remaining relatively unexplored with only ~1% of species as yet identified. It is the diversity of life below our feet that provides the engine fuelling nutrient cycling, breakdown of waste, water filtration and plant growth which is why soils are central to environmental and biodiversity monitoring.

7.2 Status and trends

The status and trend of topsoil change across Wales has been captured by the Countryside Survey since 1978. The last survey in 2007 presented changes for a wide range of physical, chemical and biological properties of soil Reynolds et al. (2013). A previous assessment of the "Critical Appraisal of State and Pressures and Controls on the Sustainable Use of Soils in Wales" was reported by Stevens et al. in 2002 which also reported on data from the National Soil Inventory as well as Countryside Survey and other data. Overall, the more recent report in 2013 indicated a picture of stable or improving soil quality with the exception of arable soils. It should be noted the methods used in CS (and other soil monitoring programmes such as the National Soil Inventory) are recognised as being inadequate for Peat Soils monitoring and thus new approaches have been commissioned within GMEP to tackle this, see chapter 2.

7.3 Aims of Glastir

The aim of the Glastir monitoring of soil quality is to collect evidence for the effectiveness of bundles of management options in helping to deliver improved soil quality that will address the outcomes of interest related to climate change, biodiversity, soil and water quality and woodland expansion. The compatibility of the current monitoring with Countryside Survey means it can draw on this data record to understand and disentangle changes in national trends from the specific impact of option bundles. The monitoring is also required to collect evidence to quantify the status and trend of water and soil quality in general for other reporting requirements and this work will provide an important counterfactual evidence base. Synthesis and analysis of this data will seek to identify how the Welsh environment is being impacted by drivers of change, such as landuse, climate and pollution over and above Glastir options. Much of the data from the soils work provides evidence for the integrated analysis, and also helps support modelling studies.

When expecting to see the impact of options it is important to consider that based on the findings of the soil quality monitoring performed under Glastir, alongside previous national surveys (e.g.

Countryside Survey), it can be expected that major changes in soil quality at the national level will not be revealed in the short-term. For example, 10 years of monitoring are typically required to reveal significant changes in many soil attributes (e.g. carbon status). Although the rolling monitoring programme implemented under Glastir has greater statistical power than previous surveys, it is still unlikely that trends in soil C will become apparent for at least 5 years or possibly longer, though it has the advantage of linking to the 30 year Countryside Survey data set which provides greater statistical power.

7.4 Benefits of past schemes

In Wales, funding from agri-environment schemes (AES) has been available since the late 80's including ESAs, the Habitat Scheme, Woodland Grant scheme, Farm and Conservation grant scheme, Tir Cymen, Tir Cynnal, Tir Gofal and now Glastir. Monitoring of farms under Tir Gofal (Anthony et al., 2012) reported that, 'Soil pH and extractable phosphorus levels were observed to be lower on Tir Gofal farms compared to non- scheme farms. However, this difference may not be due to Tir Gofal management, and was thought instead more likely to be attributable to Tir Gofal management options being applied to areas of more marginal land. Across all the remaining soil quality indicators (bulk density, erosion vulnerability, depth of peat material, organic carbon and carbon to nitrogen ratio) no positive differences were recorded between Tir Gofal and non-scheme farms.' Although the report revealed few positive benefits to soil quality in comparison to farms that had not entered the scheme, this finding could be due to several factors. Firstly, the monitoring timescales (< 3 years) may have been too short to determine significant change, secondly the pair-wise comparison of farms in and out of the scheme may have been the wrong sampling approach (i.e. not enough samples, incorrect pairing), and thirdly there may actually have been no significant benefit from the scheme. As it is impossible to resolve which of these three are valid, it is hoped that the current Glastir monitoring statistical design will help resolve these issues.

7.5 Key findings

- Topsoil (0-15cm) quality for a range of metrics has been characterised for Welsh Broad Habitats
- Analysis of Countryside Survey data with the 2013 GMEP data provides long term trend information for topsoil condition. In summary:
    - There has been no over little change in topsoil carbon concentration in Wales since 1978.
    - During the same period soil acidity was reduced probably due to decreased inputs of acidic atmospheric deposition.
    - Nutrient levels since 1998 when records started indicate no change in nitrogen levels and a stabilisation of a recent decline in soil available phosphorus levels. Levels are still acceptable for production but will have reduced the risk of phosphorus leaching to freshwaters.
    - No change in soil animal populations were found since 1998.
    - It should be noted these national topsoil statistics may mask changes within habitat types which should be reviewed individually. Of particular concern is whether arable systems are maintaining carbon levels. At the UK scale they are known to be in decline but sample numbers after only 2 years of GMEP are currently not sufficient to detect a similar level of change within Wales.
- Evidence for water and wind erosion is sparse at national scales across the UK including Wales. GMEP does not have the resources to fill this gap however we need to quantify the impacts of Glastir. We are therefore using a modelling approach which provides both erosion estimates and are of land likely to be at risk of erosion loss and mitigating sediment delivery. See the GMEP year 1 report for more information.

- No evidence of the limited samples in the Year 1 survey of any difference in topsoil quality of land coming into the Glastir scheme. This analysis will be repeated when the full Year 1-4 survey is complete.
- Exploration of the impacts of management using differences under existing land management suggests land management will change topsoil condition.
- Topsoils in Wales are incredibly diverse and appears most responsive to land management regime compared to soil type indicating Glastir has real potential to influence soil quality.
- We present a proof of concept approach for determining the area of soils for national accounting.

7.6 Main Achievements

Work to establish an effective and efficient monitoring programme for soils has been undertaken in Year 1. Major achievements include:

- Main 2014 survey
    - Trained 12 surveyors in soil sampling methods.
    - Surveyors sampled ~450 plots and collected 4 soil samples from each (~1800 samples in total).
    - CEH Labs measured cores from 435 plots to determine 45 parameters for physical, microbial, chemical, carbon and invertebrate analysis. This data supports the outcome analysis in all categories.
    - Implemented new lab protocols to improve efficiency including methods for soil water repellency using video to determine hydraulic function.
- GMEP data analysis
    - Analysed all 2013 data and submitted to the GMEP data portal.
- Soil Natural Capital Accounting
    - Proof of concept conducted combining soil and land cover data sets to assess soil resource areas under different Broad Habitats

The statistical design of the sampling is robust and intended to determine status and trend of the countryside and the Glastir options particularly those prioritised by the Welsh Government in the Advanced Element. Thus location for sampling in our Targeted Survey is proportional to the points available in the Advanced Element for different parcels of land whilst sampling methodology for national trends in soil quality has been used effectively by the Countryside Survey for the last 30 years (Reynolds *et al.*, 2013) and a similar approach is now used by the EU for the monitoring of agricultural ecosystems across Europe under the LUCAS program (Toth *et al.*, 2013).

7.7 Methods

7.7.1 Carbon and organic matter content (Loss-on-ignition)

Soil samples are collected each year in plastic sleeves, 15 cm long and 5cm wide. Loss-on-Ignition, (LOI) was measured on a 10 g air dried sub-sample taken after sieving to 2 mm. The sub-sample was dried at 105°C for 16 hours to remove moisture, weighed, then combusted at 375°C for 16 hours. The cooled sample was then weighed, and the loss-on-ignition (%) calculated. Soil carbon concentration was determined, using a total elemental analyser; the method used was the Centre for Ecology and Hydrology, Lancaster accredited method SOP3102. The LOI values were calibrated to carbon concentration using a multiplication factor of 0.55 determined from the calibration with the total carbon in order to be consistent with Countryside Survey data. For interpretation of the scale, soil type based on soil organic matter content is defined as mineral soil (0-44 g C kg^{-1}), humus-mineral (44-165 g C kg^{-1}), organo-mineral (165-330 g C kg^{-1}) and organic soil (330-550 g C kg^{-1}), the maximum carbon content is 550 g C kg^{-1}. Soil carbon density was calculated by combining with bulk density data.

7.7.2 pH

Once the 15cm soil cores from the field survey arrive back in the laboratory soil pH determination is carried out on a suspension of fresh field-moist soil sub-sampled from the core. The measurement is made in deionised water; the ratio of soil to water is 1 to 2.5 parts by weight. The method used is based upon that employed by the Soil Survey of England and Wales.

7.7.3 Nitrogen

Glastir soil samples were analysed at the Centre for Ecology and Hydrology for total nitrogen using an accredited method. Samples were analysed using an Elementar Vario-EL elemental analyser (Elementaranalysensysteme GmbH, Hanau, Germany). The Vario EL is a fully automated analytical instrument working on the principle of oxidative combustion followed by thermal conductivity detection. Following combustion in the presence of excess oxygen the oxides of nitrogen and carbon flow through a reduction column which removes excess oxygen. Carbon is trapped on a column whilst nitrogen is carried to a detector. Carbon is then released from the trap and detected separately. Sample weights are usually 15 mg for peat and 15-60 mg for mineral soil samples. The concentration of total nitrogen is expressed in % dry weight of soil.

7.7.4 C:N

The concentration of total nitrogen and carbon is expressed as a % dry weight of soil.

7.7.5 Phosphorus

Olsen-P was used to measure available phosphorus in the soil samples collected in the countryside Survey and which provides a strong argument for using the same method in Glastir to establish a time-series. The Countryside Survey began monitoring nutrients in 1998 with measurements of available phosphorus measured using Olsen-P. Olsen-P is widely used across England and Wales to assess the fertility of agricultural soils, and has also been assessed as part of several national soil monitoring schemes.

The method for Olsen-P is well established and involves extraction of 5 g of air-dried, sieved soil with 100 ml of 0.5M sodium bicarbonate at pH 8.5. The phosphorus in the extract is then determined colorimetrically using a Skalar continuous flow analyser. The Skalar method uses molybdenum blue at 880nm with the addition of a dialysis step to overcome the effect of the Olsen's reagent.
The method is known to be unreliable for acid and organic-rich soils so values for unimproved land and bogs should be treated with caution. The method was used to ensure continuity with the CS data but other methods are being tested under the NERC Macronutrient Turf-2-Surf project which we will exploit if resources are available.

7.7.6 Texture

The particle size distribution of a soil, typically presented as the proportions of clay (<2 µm), silt (2-63 µm) and sand (63-2000 µm) sized mineral particles is a fundamental property of the soil. Prior to analysis it is essential that all OM has been removed, for most soils it is recommended that hydrogen peroxide is used. The Soil Survey of England and Wales typically used a combination of the pipette method and sieving to determine the particle size of soils. There are fundamental differences between this method and the laser granulometer approach and it is necessary to use a different size threshold for the clay fraction, here we use <8 µm.

7.7.7 Bulk density

Soil samples, were collected from the field using a plastic core (15cm long and 5cm in diameter) sleeved inside a metal volumetric coring device. In the laboratory, samples were weighed and dried. Once dry, the soils were sieved, separated to 2mm fine earth fraction, and stones and debris removed. All components were weighed and the bulk density was calculated excluding stones and other debris.

7.7.8 Topsoil water repellency

Soil water repellency (surface) measurement is carried out by measuring the time for a fixed volume droplet of deionised water to be fully absorbed into the soil surface (Water Drop Penetration Time (WDPT))

7.7.9 Soil microbial diversity

Soil samples are collected each year using a soil corer. In each sampling location, 5 individual soil cores, each 15 cm long and 1 cm wide, are taken and bulked. These are then stored cold in sterile containers until they are returned to the laboratory where they are frozen at -80°C. The samples are then sieved to pass 2 mm and the DNA extracted from the whole microbial community from a sub-sample of the soil (1 g) using a MO-BIO PowerSoil® DNA Isolation Kit. The DNA is then molecular barcoded (i.e. DNA code characterised to identify different types of microorganisms present in the sample) and subjected to high throughput sequencing using the Illumina MiSeq sequencing platform at the NERC Biomolecular Analysis Facility. The sequences for bacteria, fungi, archaea and microbial eukaryotes are then processed using the bioinformatics program QIIME on the High Performance Computing Wales network.

7.7.10 Topsoil mesofauna

Soil cores are collected each year in plastic sleeves, 8 cm long and 4cm wide. The soil cores are removed from their sleeve and the mesofauna are extracted using a dry Tullgren extraction method. This consists of placing the soil cores over a mesh and gently heating and drying them by exposure to a light bulb. The soil mesofauna move downwards through the mesh into a funnel and are collected in ethanol preservative. Once collected, the different groups of soil mesofauna are sorted and counted using a stereomicroscope (up to ×100 magnification). The sum of these groups is used as an indicator of soil mesofauna abundance (or Total catch).

7.8 Results, status and trends

The results presented here also appear in the portal, they are presented as questions, most of which for the first year regard the long-term trends as compared with historic data from the Countryside Survey. As the survey progresses in time, we will be able to report on more Broad Habitats and the impact of specific bundles of options proposed in Glastir. Any detection of change will to a large degree depend on the uptake of options across the Glastir scheme. The status and trend results are shown first, then there is a short section at the end with a feasibility / scoping study of determining the Soil Natural Capital Assets in Wales, as part of improving reporting in the context of Natural Capital and Ecosystem Services in relation to national accounting.

7.8.1 What are the long term trends for soil chemical and physical properties in Wales?

7.8.1.1 Carbon

Soil organic carbon (SOC) is important for maintaining the structure and function of soils. It is involved in nutrient retention and cycling whilst enhancing soil physical structure, helping soils to retain water (reducing flood risk) and allowing improved root growth (enhancing food production). Moreover, it is an important store of carbon, which needs to be protected to avoid it being emitted to the atmosphere as carbon dioxide. A healthy soil may even accumulate more carbon over time, locking up atmospheric carbon dioxide and contributing to climate change mitigation.
Under the Kyoto Protocol the UK is required to make estimates of net carbon emissions to the atmosphere, including emissions and removals by soils linked to land-use. However, knowledge of soil carbon stocks and changes is limited; previous work from the National Soil Resources Institute and partners suggested that soils in England and Wales were losing carbon due to climate change, but this has been contested by subsequent studies based on more comprehensive soils data which suggest that the soil carbon stocks have remained stable.

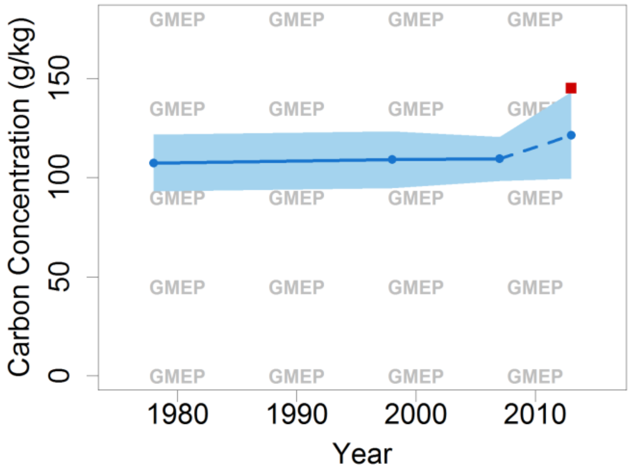


Figure 7.8.1.1.1 *GMEP data for topsoil carbon concentration for 2013 compared with data collected since 1978 by the Countryside Survey. Solid blue line (CS data); dashed blue line (GMEP 2013 Wider Wales Survey); Red squaredot (GMEP Targeted survey).*

The results for Wider Wales sampling (2013 blue circle), show that no significant change in soil carbon concentration has occurred between the last Countryside Survey sampling in 2007 and GMEP in 2013. The red square shows the Targeted sampling mean carbon concentration lying above the Wider Wales value; these GMEP 1km survey squares are monitored specifically for soil carbon and pollution. The fact they lie above indicates they are being targeted correctly.

One of the powers of the Glastir monitoring is that it helps relate soil carbon stocks to vegetation, habitat and other environmental data allowing easier assessment, and potentially better targeting of land-management activities aimed at mitigating greenhouse gas emissions. The data provided by this survey contributes to the knowledge of how soil carbon is changing, how this relates to vegetation change and land use and management and provides evidence of the effectiveness of soil protection legislation in Wales. There is generally a trade-off between maintaining high levels of soil organic carbon (SOC) and productivity. The most carbon is stored in peat bogs which are low productivity systems, whereas the least amount of SOC is stored in arable mineral soils which are continually ploughed and cropped. Fens are perhaps the exception to this being high in carbon and productivity, having been drained; but we are losing carbon from these soils. Maintaining healthy levels of soil organic matter can provide an economic buffer against market price spikes, for example against fuel and fertiliser costs in some agri-ecosystems. The soil organic matter acts as a nutrient reserve that can be accessed at times when prices are high and rebuilt in between.

The reported results are split into two groups, those representing the Wider Wales (Blue circle, 2013) part of the survey and those that represent the Targeted (Red square, 2013) part of the survey. The Wider Wales sampling is joined to the Countryside Survey long-term monitoring by the dashed line, and provides a baseline against which change can be assessed. The targeted sampling contains areas that are prioritised in Glastir for targeted options. The results presented here serve as a check to see if the samples in the targeted GMEP 1km survey squares differ from Wider Wales.

7.8.1.2 Soil acidity

Soil pH is probably the most commonly measured soil chemical parameter. It gives an indication of soil acidity and alkalinity and is of relevance to agriculture and forestry as it impacts plant growth, both directly and indirectly. Many plants have a wide tolerance of pH, but changes in pH bring about changes in the solubility of a number of important nutrients which can have an adverse effect on plant growth. Phosphorus availability decreases below pH 6, whilst some other micro-nutrients also become less available as acidity increases; calcium and magnesium may also become deficient. Moreover, if pH drops below ~5 other metal cations become soluble, particularly aluminium which is toxic to plants; manganese and iron can also be problematic becoming toxic to plants in acid soils. In Wales, recovery from acidification is important and of direct relevance to farmers and policy makers. It is currently estimated that 58% of terrestrial semi-natural habitats across Great Britain receive acidic deposition in excess of their buffering capacity thus potentially causing long term damage according to the critical load methodology. Change in soil pH has been documented by both the Countryside Survey for Great Britain and the National Soil Survey for England and Wales. Compared to Great Britain, Welsh soils are more acidic than in other countries across most Broad Habitat types. In general pH of soils has been increasing across Wales as soils recover from acidification; the results shown here are consistent with that. There is no significant change in soil pH compared with the last Countryside Survey.

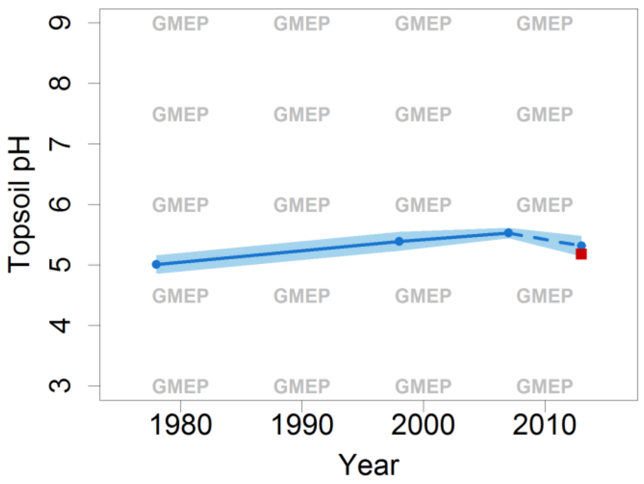


Figure 7.8.1.2.1 *Long term trends in topsoil pH using CS data (blue line); dotted line GMEP Wider Wales Survey; and re square (GMEP Targeted survey).*

The Wider Wales sampling is joined to the Countryside Survey long-term as methods were identical and together they provide a baseline against which change can be assessed. The targeted sampling contains areas that are prioritised in Glastir for targeted options. The results presented here serve as

a check to see if the samples in the targeted GMEP 1km survey squares differ from Wider Wales. The results show both samples are not significantly in contrast to carbon concentrations.
Evidence from Countryside Survey indicates that soils are recovering from air pollution and acidification and the Glastir Monitoring and Evaluation Program data is consistent with that. This provides benefits to growers who require less inputs like lime to raise pH, it is also good for plant life and biodiversity. However, there may also be a trade-off with carbon storage, as more carbon is stored in acidic soils. This will be something to watch and determine from the Glastir survey, whether changes in carbon concentration are observed between acid and neutral and improved grasslands.

Results from the Countryside for particular Broad Habitats show that the most acid soils in Wales in 2007 were those beneath Coniferous Woodland (pH 4.14), whilst soils beneath enclosed farmland Broad Habitats were the least acid. Since 1978 the average pH of improved and neutral grassland has been increasing, with mean values approaching pH 6 in 2007.

7.8.1.3 Nitrogen

Nitrogen (N) availability commonly limits plant productivity, and so is important for determining agricultural and forest production and as a control on plant diversity. Soil total nitrogen concentration is a basic indicator of soil fertility so to a limit is desirable in agricultural and forestry soils but undesirable in habitat / conservation areas. Soil total nitrogen concentration generally increases with organic matter content, and so is greater on infertile peaty soils, but within a particular soil type an increase in concentration, particularly when expressed relative to carbon concentration, implies that nitrogen is accumulating. Most soils have a large stock of relatively unreactive nitrogen, so total nitrogen concentration is relatively insensitive to short-term changes, but over a longer time period gives an overall indication of trend in soil fertility and change in nutrient status in relation to other parameters such as carbon. Changes in plant species composition, primarily homogenisation with loss of specialist species, were observed following the Countryside Survey in 1998 and these were ascribed to ecosystem nitrogen pollution following enhanced deposition of atmospheric nitrogen compounds which are emitted from both agricultural sources (animals and fertilisers) and combustion of fossil fuels (e.g. within the transport & energy sectors).

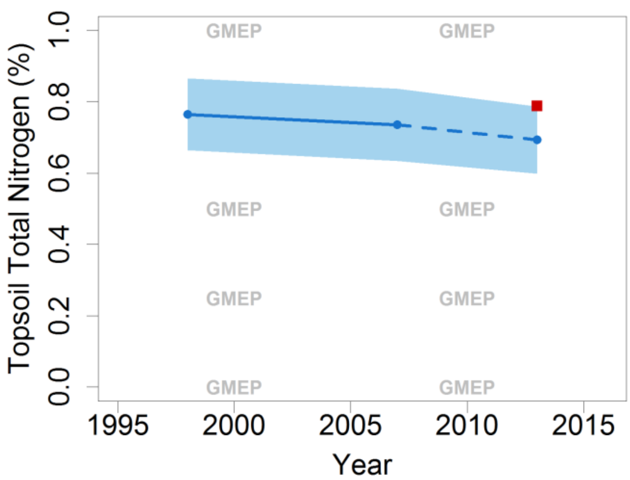


Figure 7.8.1.3.1 *Long term trends in topsoil total nitrogen content using CS data (blue line); dotted line GMEP Wider Wales Survey; and re square (GMEP Targeted survey).*

The Wider Wales sampling is joined to the Countryside Survey long-term monitoring and provides a baseline against which change can be assessed. The targeted sampling contains areas that are prioritised in Glastir for targeted options. The results presented here serve as a check to see if the samples in the targeted GMEP 1km survey squares differ from Wider Wales. There was no significant change in soil nitrogen concentration across Wales as a whole between 1998 and 2007 or between 2007 and 2013.

Enhanced soil nitrogen status can influence plant species assemblages in two ways. Reactive nitrogen limits plant production in many terrestrial ecosystems, so increased exposure to anthropogenic nitrogen is likely to result in increased plant growth. Consequent changes to competitive interactions have been implicated as a cause of plant diversity loss. Secondly, some plants are known to respond to changes in the ratio of available ammonium to available nitrate in the soil.

7.8.1.4 C:N

The soil nitrogen concentration data were combined with total carbon concentration data to calculate changes in soil carbon to nitrogen ratio (C:N) (0-15 cm). The C:N ratio is more informative about the availability of reactive nitrogen than is the nitrogen concentration in soil. Countryside Survey didn't have enough data to report change in C:N ratio for Wales, but provided general data for Great Britain. Tir Gofal monitoring found no difference between control and Tir Gofal managed sites.

Habitat	Indicator	CS 1998	CS 2007	GMEP 2013	Significant differences
Broadleaved, Mixed and Yew Woodland	Mean C/N ratio	14.0	14.2		
Coniferous Woodland	Mean C/N ratio	20.1	21.5		⇧ 98-07
Arable and Horticulture	Mean C/N ratio	11.7	11.3		⇩ 98-07
Improved Grassland	Mean C/N ratio	11.8	12.0		
Neutral Grassland	Mean C/N ratio	12.3	12.7		⇧ 98-07
Acid Grassland	Mean C/N ratio	17.7	18.2		
Bracken	Mean C/N ratio	15.2	16.5		
Dwarf Shrub Heath	Mean C/N ratio	22.9	23.1		
Fen, Marsh and Swamp	Mean C/N ratio	16.4	17.7		
Bog	Mean C/N ratio	26.2	28.2		
All Habitat types	Mean C/N ratio	15.6	16.0		⇧ 98-07

Table 7.8.1.4.1 *Topsoil C:N change over time for CS and GMEP habitats and Wales as a whole.*

Countryside Survey data showed that the general trend across all Broad Habitats in Great Britain is for no change or an increase in carbon to nitrogen ratio (C:N). The trend for increased C:N ratios (significant for Coniferous Woodland and Neutral Grassland) indicates that there is either increased removal of nitrogen from the soil by vegetation, leaching or gaseous pathways and / or greater inputs and storage of carbon due to increased plant productivity. Change in plant fixation of carbon and uptake of nitrogen may be driven by the combined and possibly interactive effects of nitrogen deposition and climate change on plant productivity.

For cropped systems, a decline in % nitrogen and C:N ratios was observed for Great Britain suggesting the loss of soil carbon (0-15cm) found in Countryside Survey for these habitats is matched by a loss of nitrogen (9 and 7.5% respectively between 1998 and 2007). As there was only a small decline in nitrogen fertiliser application rates to tilled land across Great Britain between 1998 and 2007 (e.g. in England 6% drop for tilled land), it is most likely that processes which would remove soil carbon and nitrogen in equal proportions may be responsible e.g. erosion or deep ploughing resulting in lower soil horizons characterised by lower C:N coming to the surface. Lower values in improved grass suggest too much nitrogen, nitrogen levels were still high in 2007 in improved grass.

7.8.1.5 Phosphorus

Olsen-Phosphorus (Olsen-P) is one of a number of measures of available phosphorus. Phosphorus is one of the three macronutrients, nitrogen and potassium being the others, that plants need a lot of for growth, and are key inputs in NPK fertilizer. High Olsen-P levels had been observed in agricultural, especially arable, soils where excessive applications of phosphorus had been made. Efforts have been made over the last few decades to reduce inputs and bring phosphorus levels down to increase efficiency and reduce waste and pollution.

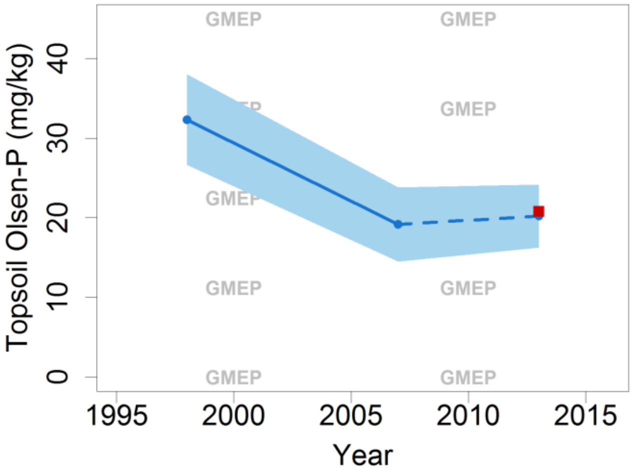


Figure 7.8.1.5.1 *Long term trends in topsoil phosphorus availability (Olsen-P) using CS data (blue line); dotted line GMEP Wider Wales Survey; and re square (GMEP Targeted survey).*

The Wider Wales sampling is joined to the Countryside Survey long-term monitoring and provides a baseline against which change can be assessed. The targeted sampling contains areas that are prioritised in Glastir for targeted options. The results presented here serve as a check to see if the samples in the targeted GMEP 1km survey squares differ from Wider Wales. The results show both samples are not significantly different.

Overall the data for Glastir probably indicates a stabilising of Olsen-P levels in Welsh soils, but cannot be confirmed until Countryside Survey and GMEP are run in the same year. This follows on from data collected by the Countryside Survey which reported that Olsen-P values declined across Wales between 1998 and 2007 across all Broad Habitats (41%). The largest significant decrease (47%) was in the Improved Grassland Broad Habitat. This is consistent with data on fertiliser use compiled by Defra for England and Wales, which shows fertiliser inputs on grasslands have decreased dramatically since the 1980's.

Managing available P levels in the agricultural context will reduce the risk posed by phosphorous in surface water (< 20 µg/l) which can cause detrimental effects to water quality. Moreover, applying excess fertilizer to land simply results in losses and wasted economic investment. The scientific benefit of using Olsen-P is that it has been widely used in England and Wales to assess the fertility of agricultural soils and is also an integral part of several national soil monitoring schemes including the Representative Soil Sampling Scheme, the National Soil Inventory and Countryside Survey.

7.8.2 Is there any evidence of a difference in soil condition of land coming into the Glastir scheme?

Setting a base line is important, and in this first year of Glastir we want to determine if the soils selected for the Glastir scheme differ from soils that are not selected for Glastir. In future years, this will help us to determine the impact of being in Glastir for soil quality and health. The data is limited at present due to only one year of data being available out of the total four years of baseline to be collected. Improved power of detection of differences are likely as sample size increases.

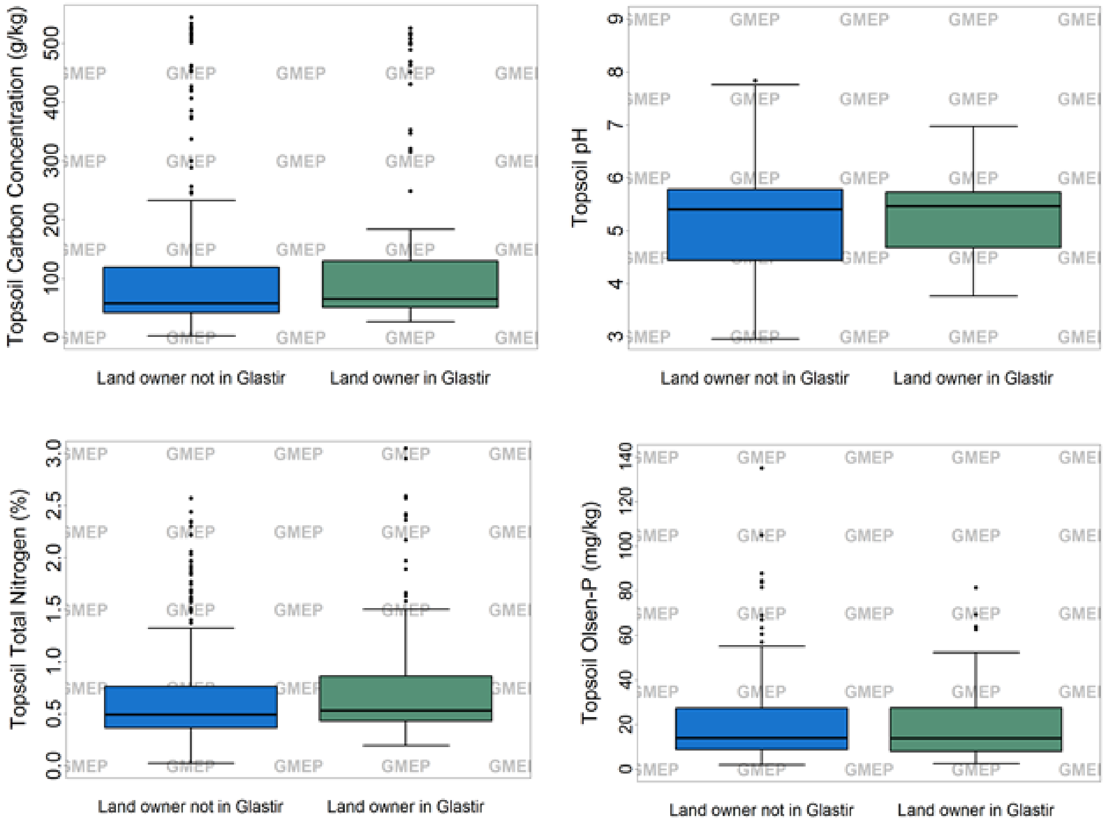
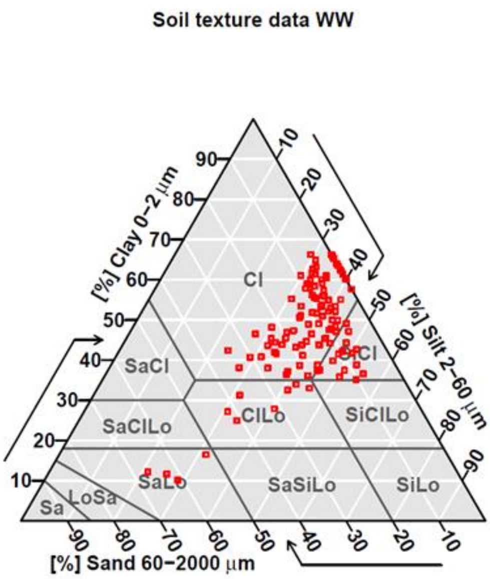


Figure 7.8.2.1 *Soil chemical properties of land in and out of the Glastir scheme in 2013; carbon, pH, total nitrogen and available phosphorus (Olsen-P). The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots. There are currently no significant differences between soil chemical properties on land in and out of scheme.*

Soil texture is a classification of the size of particles in soil and describes the amount of sand, silt and clay. It is a description of the fabric of a soil and is important for agricultural practice and engineering as well as underpinning much of the science of soils. The texture impacts both the physical and biogeochemical behaviour of soil. The smaller the soil particles are, the more reactive surface area they have. It is on these surfaces that nutrients are stored or transformed. Soil texture is important for assessing physical flow and transport behaviour as well as erodability, and workability. The most detailed survey of soil texture is held by the Soil Survey of England and Wales.



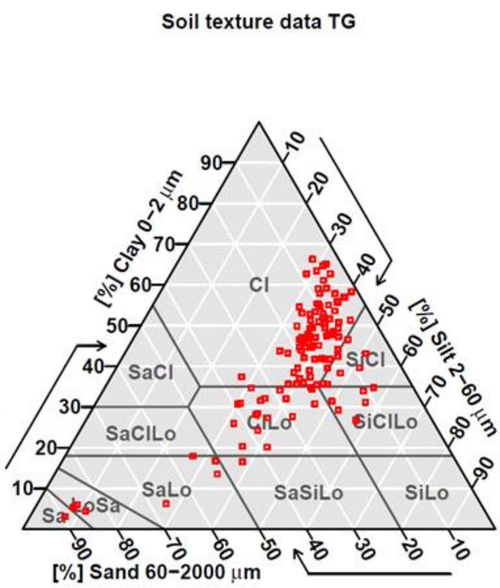


Figure 7.8.2.2 *Textures for soil of land in and out of Glastir in 2013.*

The data shows the soil textures for samples measured in the Wider Wales (WW) GMEP 1km survey squares which are representative of Wales. The second figure shows soil texture for the Targeted (TG) GMEP 1km survey squares, which were chosen by the Welsh Government for specific targeted options. The data show that much of Wales has a high proportion of clay and clay loam soils and there are subtle differences between soil texture of land coming into the scheme which we explore as more samples come in.

7.8.3 Is there any evidence that the soil condition is higher in soils which were in past AES schemes, Tir Gofal, Tir Cynnal, compared to those that were not in schemes?

Setting a base line is important, and in this first year of Glastir we want to determine if the legacy from past agricultural environment schemes (AES), e.g. Tir Gofal, Tir Cynnal, has had any detectable influence on the soils across Wales with regard to altering carbon concentrations.

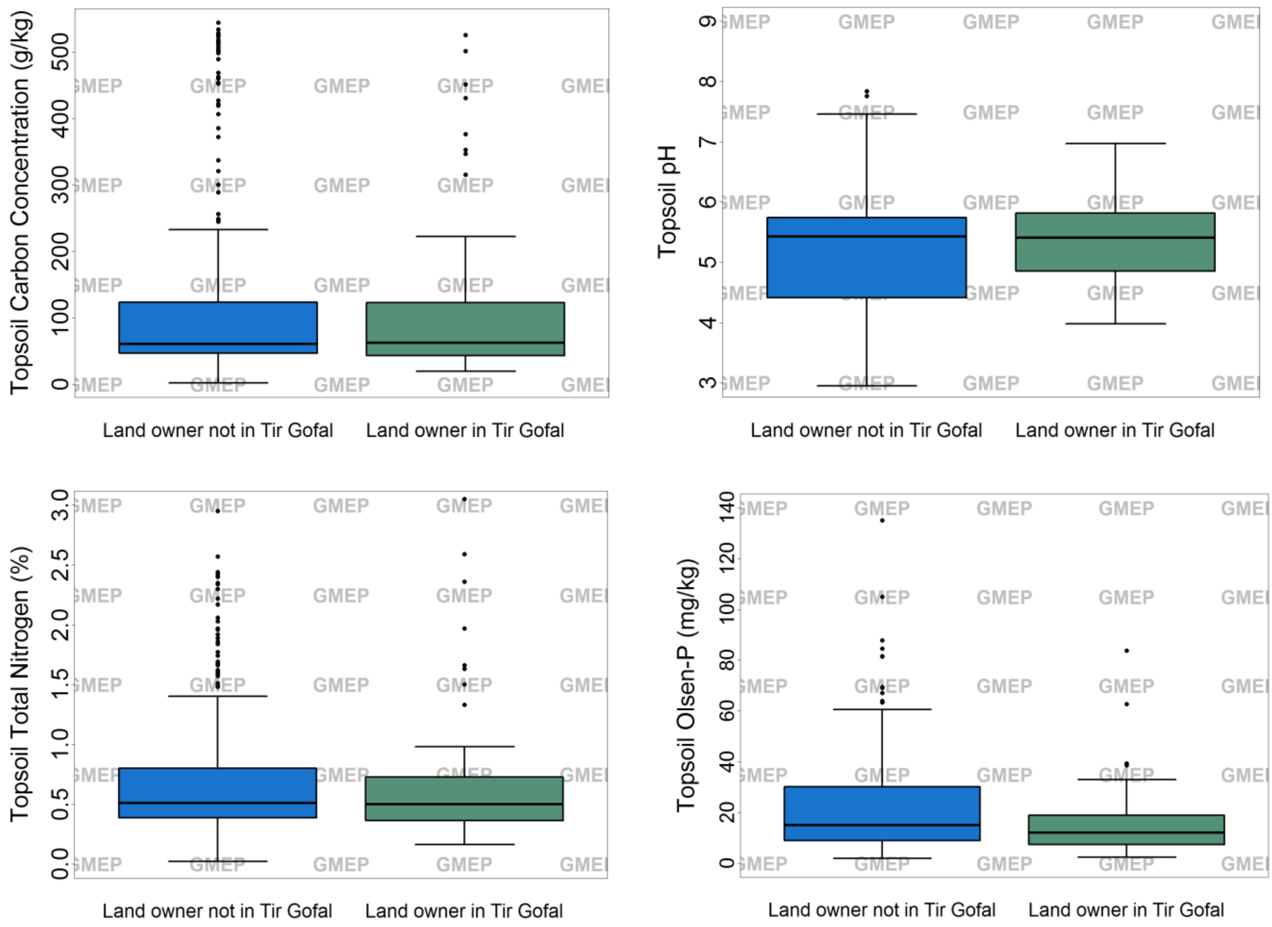


Figure 7.8.3.1 *Condition of soils that were in a past agri-environment scheme, e.g. Tir Gofal, or Tir Cynnal in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

Data indicates there is not a significant difference between the two groups. However, it is noticeable that the lower range of the Tir Gofal managed plots is higher than those outside a scheme. This might indicate that the soils selected for the scheme had higher carbon, or management practices have increased carbon levels. The boxplots show that there is no statistical difference between the pH of soils where the landowner was in Tir Gofal versus a landowner that was not in Glastir. The results do however indicate that the range of soil pH for the soils entered into Tir Gofal is narrower than those outside, which may be a function of the land entered in the scheme rather than a change. The Tir Gofal monitoring program found that Olsen-P levels were similar between sites, other than with some of the neutral grassland sites under prescription 32 A/B (‘Conversion of Improved Grassland to Semi-improved Grassland’ with no lime or fertilizer to be spread). The difference between sets of Tir Gofal prescription and ‘control’ sites was not thought to be due to the influence of the Tir Gofal scheme itself, but rather due to the fact that Tir Gofal prescriptions tend to be allocated to sites where extractable P is lower. This reflects the tendency for Tir Gofal prescriptions to be located on sites of lower potential productivity (relative to non-Tir Gofal prescription sites) and with a history of minimal or no lime and fertiliser use. Within GMEP Year 1 samples, the available phosphorous levels are significantly lower on the land that was under agri-environment scheme management. According to the Tir Gofal report, this was most likely due to the land being entered into the scheme having lower available phosphorous to start.

7.8.4 How do soils vary in condition by Broad Habitat?

7.8.4.1 Carbon

Soils represent a major terrestrial carbon store that we want to protect for both soil quality, hydraulic function and to protect against climate change. We need to understand which habitats have the highest carbon concentrations and seek to maintain these.

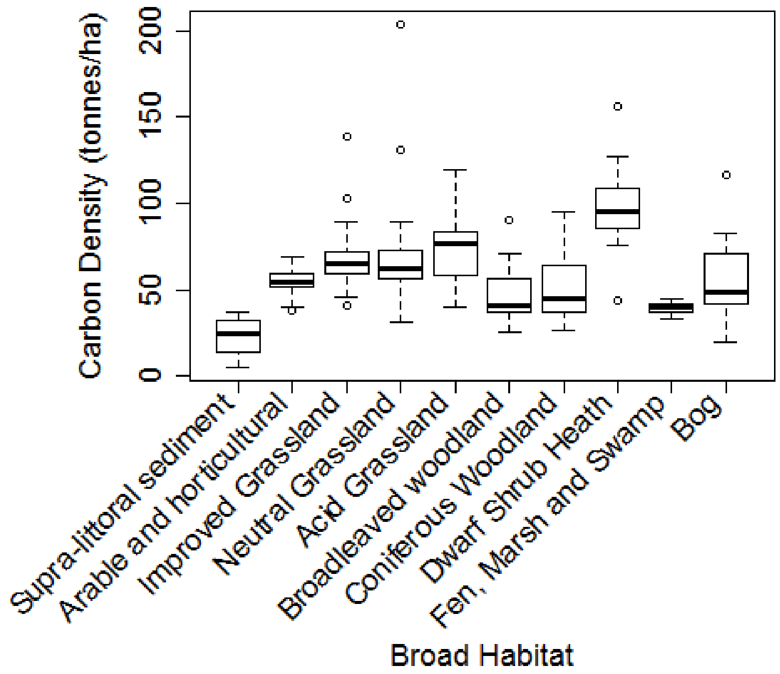


Figure 7.8.4.1.1 *Topsoil (0-15 cm) carbon density within different Broad Habitats across Wales in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

The highest topsoil stocks are in the heath and grassland soils; most likely in the heathlands as they are often associated with organo-mineral soils with a dense organic soil horizon. Grasslands on the other hand contain high concentrations of carbon and are relatively dense. Countryside Survey reported that between 1978 and 2007 there had been no change in the carbon stocks in fertile or infertile grassland. It is important to remember that these figures are only for topsoils (0-15 cm), where we would expect to see the greatest levels of change. Peat soils represent the largest overall soil carbon store because, accounting for high soil organic carbon below this depth, they are greater than 40 cm deep, and often several metres.

7.8.4.2 Soil acidity

It is useful as a baseline for future assessment of GMEP data to know how topsoil pH changes across habitats. The data indicates that more than 75% of neutral and improved grasslands have soil pH above 5. Bogs, Coniferous Woodlands and Dwarf shrub heath all have the lowest values of pH with more than 75% of the data below pH 5. The 2008 UK Soil Indicators Consortium assessed values for soil pH to ‘prompt’ management action. The testing of these prompt values suggested that managed grasslands should aim to maintain soil pH values above 5, and dwarf shrub heath above pH 4.5, to maintain habitat support.

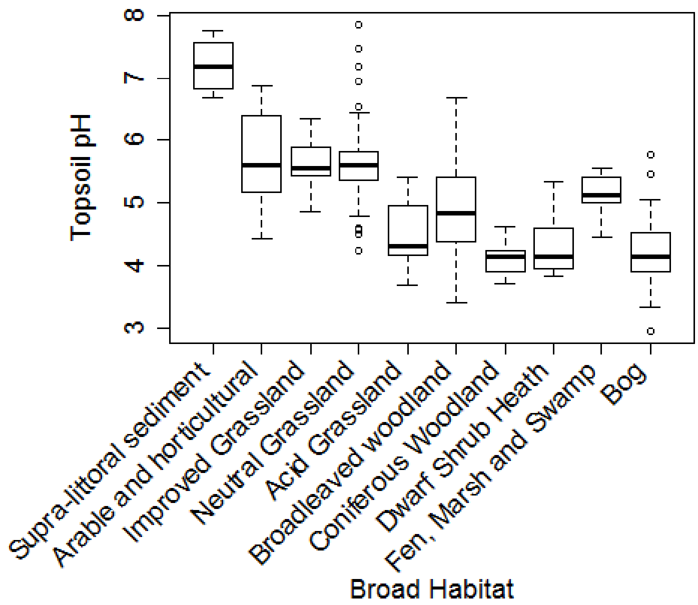


Figure 7.8.4.2.1 *Topsoil pH across Welsh Broad Habitats in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

7.8.4.3 C:N

The soil nitrogen concentration data were combined with soil carbon concentration data to calculate the soil carbon to nitrogen ratio (C:N) (0-15cm). The C:N ratio is more informative about the availability of reactive nitrogen than is total nitrogen concentration in soil. The 2008 UK Soil Indicators Consortium proposed ‘prompt value’ ranges for C:N within which a habitat should sit for optimal function:
Calcareous grassland 11-14
Neutral grassland 10-14
Broadleaf woodland 12-17
Coniferous woodland 16-26
Improved grassland 10-12
Acid grassland 14-21
Arable and horticultural 9-13
Bog 20-31
Dwarf Shrub Heath 19-29
Bracken 13-18
In an indicator testing exercise they found that the ranges were too narrow, and so we propose these ranges be viewed as desirable values.

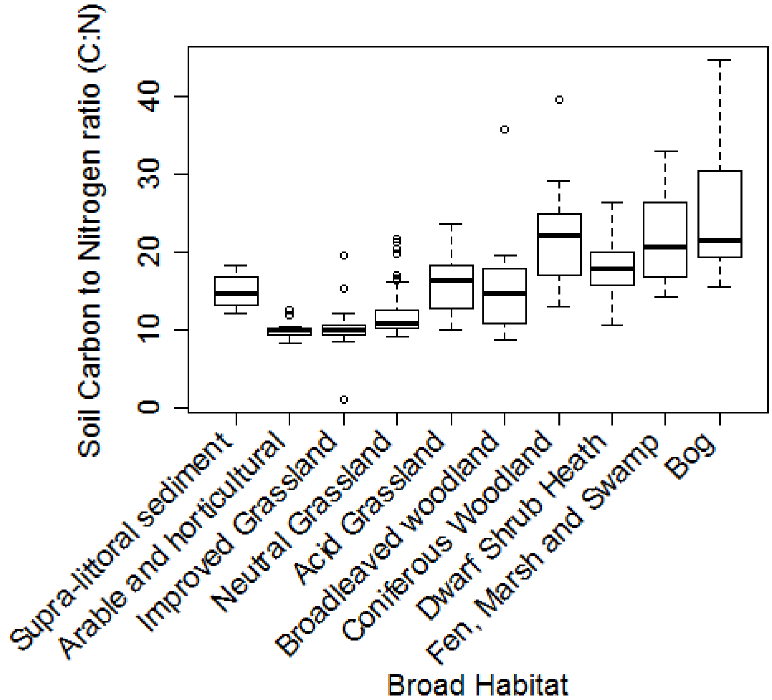


Figure 7.8.4.3.1 *Topsoil C:N ratios for Welsh Broad Habitats in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

Countryside Survey data showed that the general trend across all Broad Habitats in Great Britain is for no change or an increase in C:N ratio. The boxplot shows that for the Broad Habitats measured by Glastir Monitoring and Evaluation Program across Wales all the middle values fall within the expected range for habitat support. Generally we might be concerned if C:N ratios were declining below 10 for neutral and improved grassland as this might indicate more reactive nitrogen in the soil system.

7.8.4.4 Phosphorus

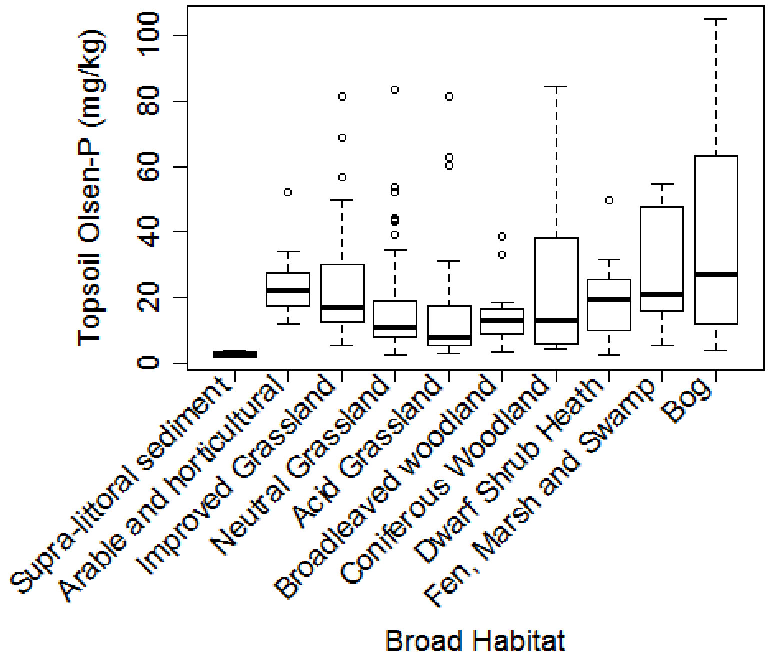


Figure 7.8.4.4.1 *Topsoil available phosphorus (Olsen-P) for Welsh Broad Habitats in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

Following the management intervention prompt values proposed by the UK Soil Indicators Consortium we propose that values for agricultural soils should not exceed 60mg/kg, whilst for grass lands, keeping below 15mg/kg is advisable to maintain habitat support. The Soil Indicators Consortium's general finding was that it was hard to provide specific prompt values for such a diversity of communities. In testing their prompt values they suggested that 30% of acid grasslands exceeded a prompt value of 10 mg/l and still had valuable species; whilst the value of 16 mg/l for calcareous grasslands should probably be brought down to 10mg/l. It appeared that a prompt value was not particularly appropriate for neutral grasslands. As a consequence we've suggested a prompt value of 15mg/kg as a guide suggesting 75% of acid grasslands should fall below this level. In the future, co-located soil and plant measurement data from the Glastir survey will help us to identify prompt values most suitable for the Welsh countryside.

7.8.4.5 Bulk density

Soil bulk density (BD) is the single most useful parameter for assessing soil physical structure and porosity. It is a direct measure of soil compaction (or loosening) and is essential to assess total available pore space within a soil (that is, total porosity). This question seeks to determine the general status of Welsh soils with regard to bulk density. Compacted soils act as a focus for storm water runoff and soil erosion whilst inhibiting the growth of plant roots. There is usually a strong relationship between bulk density and soil organic carbon content, the bulk density decreasing, and porosity increasing, as organic carbon increases.

The boxplots show bulk density declining from the habitats dominated by mineral soils to those dominated by organic soils like the upland bogs. No definitive 'trigger points' have been identified, or agreed, for bulk density for all soils by the 2008 UK Soil Indicators Consortium. However, 'prompt' values above which mineral and peat soils in grasslands and heaths are liable to be suffering from compaction have been proposed. These are 1.3 gcm^3 for mineral soils and 1.0g/cm^3 for peat soils. All grassland and heath soils were below prompt values, except one of the improved, and one of the neutral grassland sites. Further investigation indicated this was not simply due to high sand content and might indicate compaction. The Supra-littoral Broad Habitat has the highest values which are associated with sandy soils which we commonly expect to have bulk densities in the region of 1.4-1.6 g/cm^3. The data findings are in broad agreement with the Tir Gofal monitoring which also found very few soils above 1.3gcm^3 and no difference between control and sites in the Tir Gofal scheme.

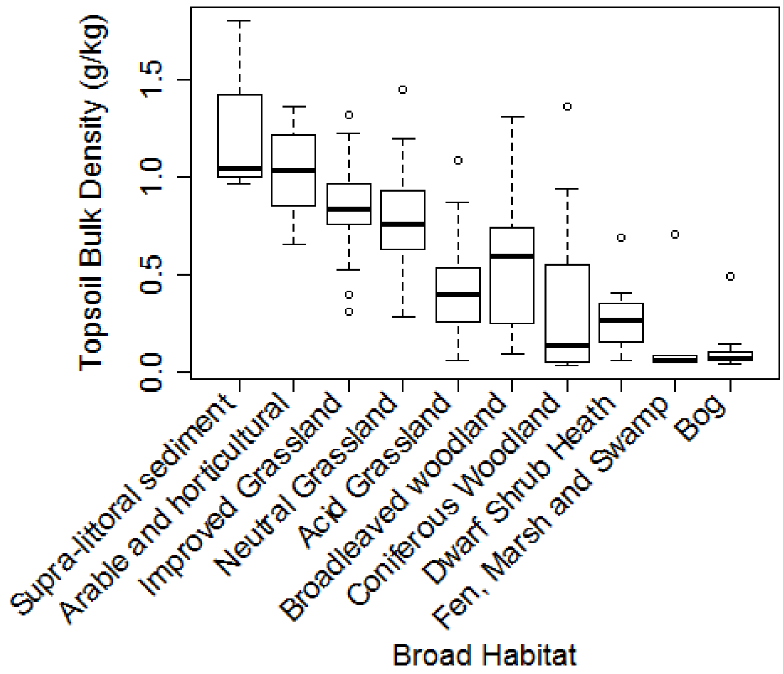


Figure 7.8.4.5.1 *Topsoil bulk density in Welsh Broad Habitats in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

7.8.5 What is the potential for land management to change soil condition

GMEP in the long term will be able to address this question but in the meantime we have three approaches to start exploring this issue; a) assessment of past AES scheme outcomes, b) experimental data and c) comparing data from different land management/uses. All have some fundamental problems.

a) Past AES scheme monitoring have struggled to separate differences of land coming into the scheme from the effect of the scheme;
b) Experiments frequently being too short term to quantify change thus making assessments e.g. for inventory work challenging
c) An assumption that current changes are due to land management rather than pre-existing differences before the land management took place.

Despite these differences, we have undertaken two of these analyses using the GMEP data. See Section 7.8.3 for a discussion on soil quality from past AES schemes. Here we explore the differences in soil condition under different land management types. For a summary of experimental evidence this has been summarised most effectively recently with respect to grassland management for the Land Use, Land Use Change and Forestry Inventory (see http://ecosystemghg.ceh.ac.uk/).

7.8.5.1 Is carbon concentration increasing under Improved Grassland?

Results from the Countryside Survey (Emmett et al., 2010) indicated that there had been an increase in the carbon concentration in fertile grasslands and a decline in infertile grasslands. Although not statistically different, it indicated a general direction of change. The Glastir monitoring will seek to determine if differences and changes in carbon concentrations in grassland systems can be detected. Not sufficient GMEP data yet, but evidence from Countryside Survey 2007 presented in the figure shows the change in soil C concentration (0-15 cm) for Wales between 1978 and 2007 for fertile and infertile grassland. No significant change was observed. Clearly the increased number of samples within GMEP will enable us to detect change with greater power.

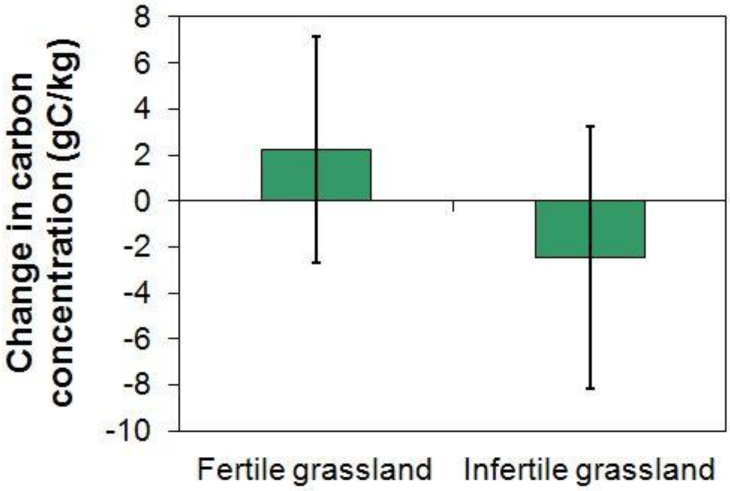


Figure 7.8.5.1.1 *Change in soil C concentration (0-15 cm) for Wales between 1978 and 2007 for fertile and infertile grassland (Countryside Survey data). Bars indicate 95% Confidence Intervals.*

7.8.5.2 Is soil water repellency greater in woodlands compared to grassland and other habitat types?

Soil water repellency (SWR) is a measurement of how wettable the soil surface is. It alters the way water infiltrates into soils potentially enhancing infiltration in soils with big pores like many woodlands, hence reducing flood risk. Recently SWR has also been linked to the increased stabilization of carbon in soils by protecting organic matter from breakdown by microbes and enzymes (Goebel et al., 2011). Schmidt et al. (2011) touched upon this role of SWR when reviewing our understanding of soil carbon as an ecosystem property. The Glastir monitoring program is the first UK survey to contain this measurement. Often only considered an issue in Mediterranean-type climates it is increasingly being observed in temperate climates and has been shown to be damaging to UK agriculture, for instance potato production in East Anglia. Our scientific understanding of the development and persistence of soil water repellency is still not mature. However, its presence can lead to erratic behaviour with regard to water movement in soils. Some may be aware of the problems green keepers have with dry spots on golf courses, this is induced by water repellency and causes the grass to die. Moreover, it affects the way water infiltrates into soils and may impact nutrient cycling. Given concern over extreme weather events, drought and flooding, anything that changes how rainfall infiltrates, or runs off at the soil surface in response to extremes is of both agronomic and policy interest. In Mediterranean climates soil water repellency is often associated with forestry. Therefore, land use change to forest from other land uses may alter the way water runs off the landscape.

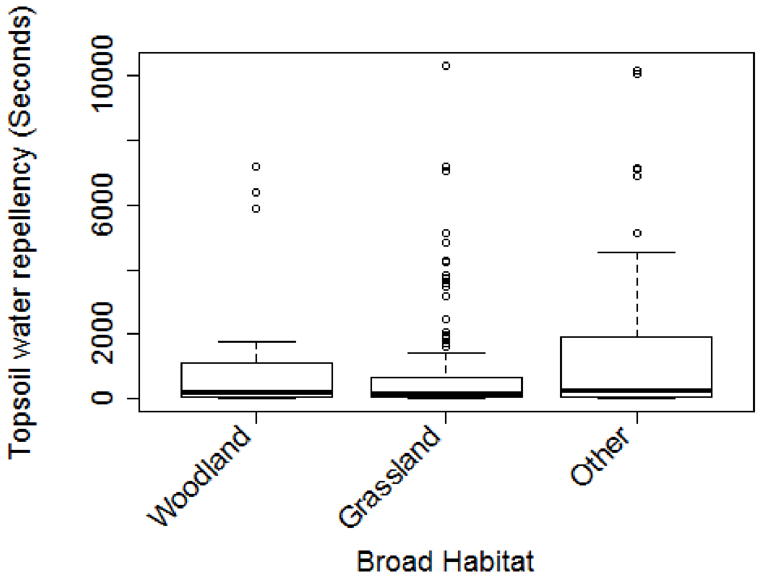


Figure 7.8.5.2.1 *Topsoil water repellency for three habitat groups in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

The data are currently limited and have been aggregated together into woodland, grassland and other habitat types. At this level of aggregation the 'other' category have the most repellent soils, (average = 1452 seconds) whilst the woodlands (average = 1043 seconds) are more repellent than the grasslands (average = 663 seconds). However, the average for the grasslands still puts them in the severely water repellent class according to the Dekker and Ritsema classification; wettable soils are those into which a water drop enters in less than 5 seconds. The test whether this is linked to land use or inherent soil properties will be explored as land is re-visited which have changed from e.g. from grassland to woodland.

Our understanding of the disadvantages of soil water repellency are best understood, potentially causing dry-patches in turf or enhanced runoff and erosion after fire. Our understanding of the benefits is much more limited, but recent research in drylands suggests that water repellency can be an advantage, enhancing infiltration through macropores and moisture storage and increasing soil organic matter stability in soils. Others have suggested that repellent soil may protect nitrogen preventing its rapid mineralisation. The relationship with flood risk is not known, but in soils with plenty of macropores soil water repellency might reduce flood risk, the converse may also be true. Many Glastir options will lead to changes in the composition of the vegetation community and will also alter key properties and functions of the soil. This is likely to lead to changes in the soil microbial community (e.g. bacteria, fungi, archaea, protozoa, collembola, earthworms etc.). These could impact on a range of ecosystem services linked directly and indirectly to the soil microbial community including: (1) the recycling of nutrients within the plant-soil system, (2) regulating the balance between the release of greenhouse gases and the sequestration of carbon in soil, (3) the decontamination of organic pollutants, (4) enhancing plant growth through symbiotic relationships, (5) the provision of food for birds, (6) the purification of water, and (7) regulating soil structure and water infiltration.

7.8.6. What is the current status of soil biodiversity in Wales and what influences its spatial and temporal pattern?

7.8.6.1 How does soil microbial diversity differ across Broad Habitat types in Wales?

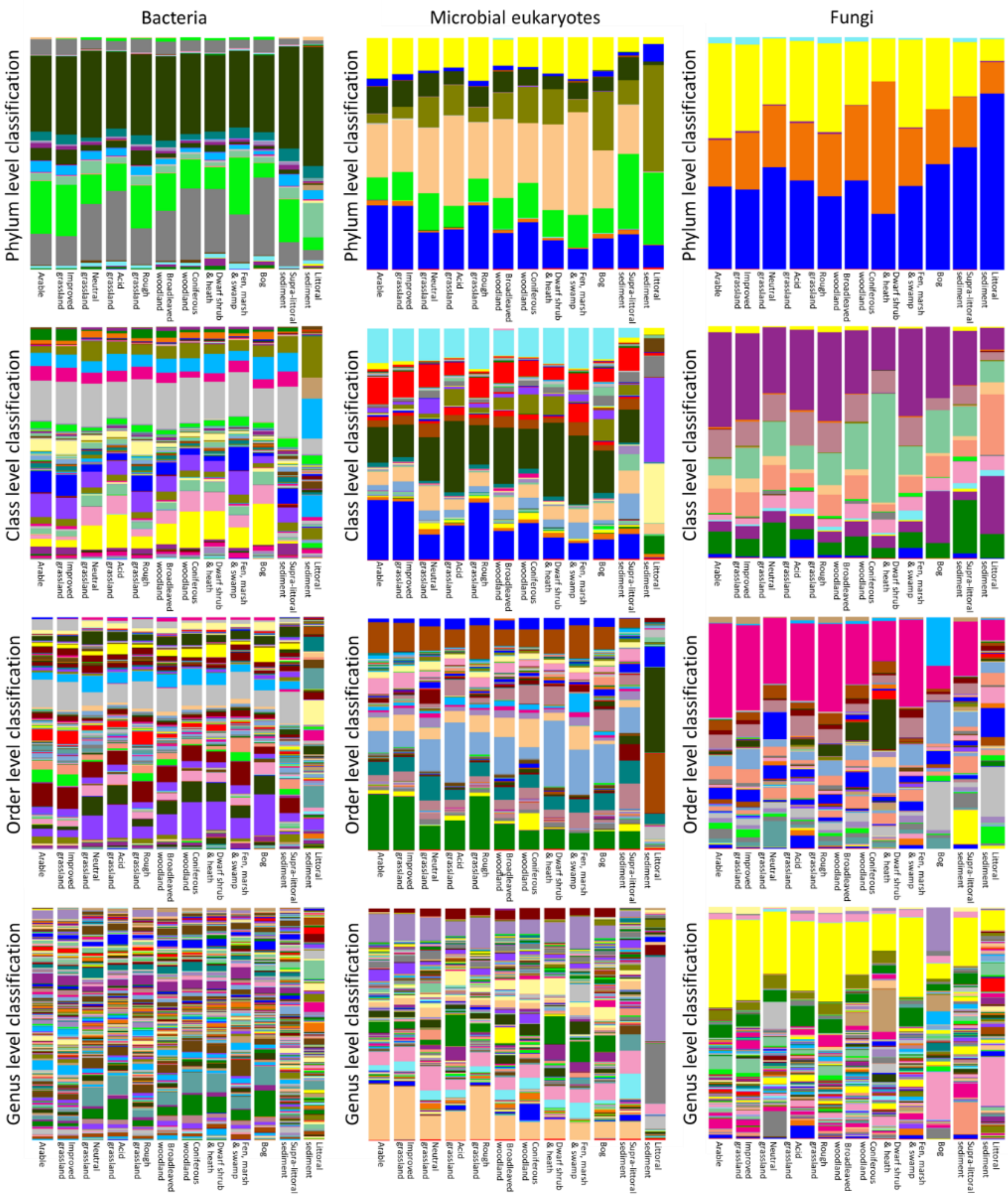


Figure 7.8.6.1.1 *Bacterial, non-fungal eukaryotes and fungal communities at a range of taxonomic levels starting at the highest level (Phylum level) and ending at the lowest level (Genus level) for Broad Habitat types in Wales in 2013. The coloured bars represent different bacterial and fungal types at each taxonomic level. At the lowest taxonomic level (Genus), some coloured bars are too small to be seen (i.e. genus of low abundance).*

The reported results show that Broad Habitat types in Wales have unique microbial communities and thus land use has a major impact on the structure of soil microbial communities. This can be seen when the microbial communities are classified by Broad Habitat type. The figure below shows bacterial community composition at a range of taxonomic levels (Phylum → Class → Order → Genus) for 12 different Broad Habitat types within Wales. It is clear that each Broad Habitat has a unique community composition and that these are most apparent at the lower taxonomic levels (e.g. genus level). Of particular note are that improved grassland and arable soils have very similar community compositions. These, however, are vastly different from unimproved grasslands suggesting that land use change and a reduction in inputs (e.g. fertiliser, lime) will induce shifts in community composition. Littoral soils showed a vastly different community composition in comparison to all other Broad Habitat types. This is the first ever holistic survey of soil biodiversity in Wales and consequently we cannot evaluate how this is changing over time.

Although our knowledge of soil biodiversity is still in its infancy we know that the soil community underpins a wide range of ecosystem services which are being promoted under Glastir. The current consensus is that a more biodiverse community will also be more resilient to stress conditions. In addition, it is also apparent that microbial communities respond to change and therefore act as sentinels of change. In Glastir we are therefore looking for soils that have high levels of diversity which should be promoted by reducing fertiliser inputs, by planting trees at low density and via the enhanced storage of organic matter. In addition, we are looking for shifts in keystone species which control processes associated with greenhouse gas emissions (e.g. methanogens), nutrient cycling (e.g. nitrifiers), water repellency (e.g. fungi) or animal disease and loss of water quality (e.g. *E. coli*). There is the potential for ecosystem trade-offs in shifts in the microbial community. For example, a reduction in the number of nitrifiers may reduce greenhouse gas emissions and nitrate leaching, but this may limit the supply of available nitrogen to grassland, forage crops etc.

7.8.6.2 How does soil organic carbon affect microbial biodiversity in the soils of Wales?

Sequestering more carbon in Welsh soils is a key goal of Glastir as this is known to improve soil quality and also help reduce climate change. Many Glastir options will lead to changes in soil organic carbon which are likely to lead to changes in the structure and activity of the soil microbial community (e.g. bacteria, fungi, archaea, protozoa, collembola, earthworms etc.). These could impact on a range of ecosystem services linked directly and indirectly to the soil microbial community including: (1) the recycling of nutrients within the plant-soil system, (2) regulating the balance between the release of greenhouse gases and the sequestration of carbon in soil, (3) the decontamination of organic pollutants, (4) enhancing plant growth through symbiotic relationships, (5) the provision of food for birds, (6) the purification of water, and (7) regulating soil structure and water infiltration.

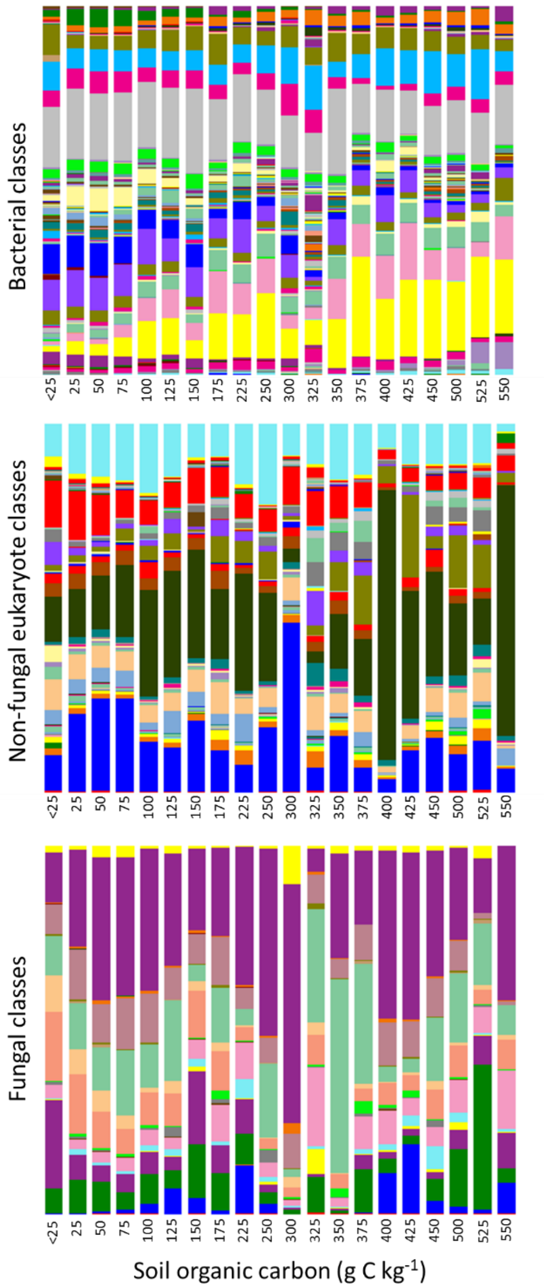


Figure 7.8.6.2.1 *The relative abundance of bacterial, non-fungal eukaryotes and fungal communities living in the soil for different soil organic carbon contents in 2013. The microbial communities are presented at the Class taxonomic level. The coloured segments in each bar represent the relative abundance of different bacterial, non-fungal eukaryotes and fungal taxonomic classes.*

The results show that soil organic matter status has a major impact on the structure of soil microbial communities. This is most apparent in the types of bacteria present in the soil with trends less apparent in the fungal and non-fungal eukaryotes. The results suggest that changes in soil organic matter status will induce a shift in soil microbial communities. It should be noted that the amount of soil organic carbon and pH are closely correlated and it is likely that bacterial diversity is responding to both an increase in soil organic matter and reduction in pH simultaneously.

7.8.6.3 How does soil pH affect soil microbial biodiversity in the soils of Wales?

Many Glastir options will lead to changes in soil pH which are likely to lead to changes in the soil microbial community (e.g. bacteria, fungi, archaea, protozoa, collembola, earthworms etc.). These could impact on a range of ecosystem services linked directly and indirectly to the soil microbial community including: (1) the recycling of nutrients within the plant-soil system, (2) regulating the balance between the release of greenhouse gases and the sequestration of carbon in soil, (3) the decontamination of organic pollutants, (4) enhancing plant growth through symbiotic relationships, (5) the provision of food for birds, (6) the purification of water, and (7) regulating soil structure and water infiltration.

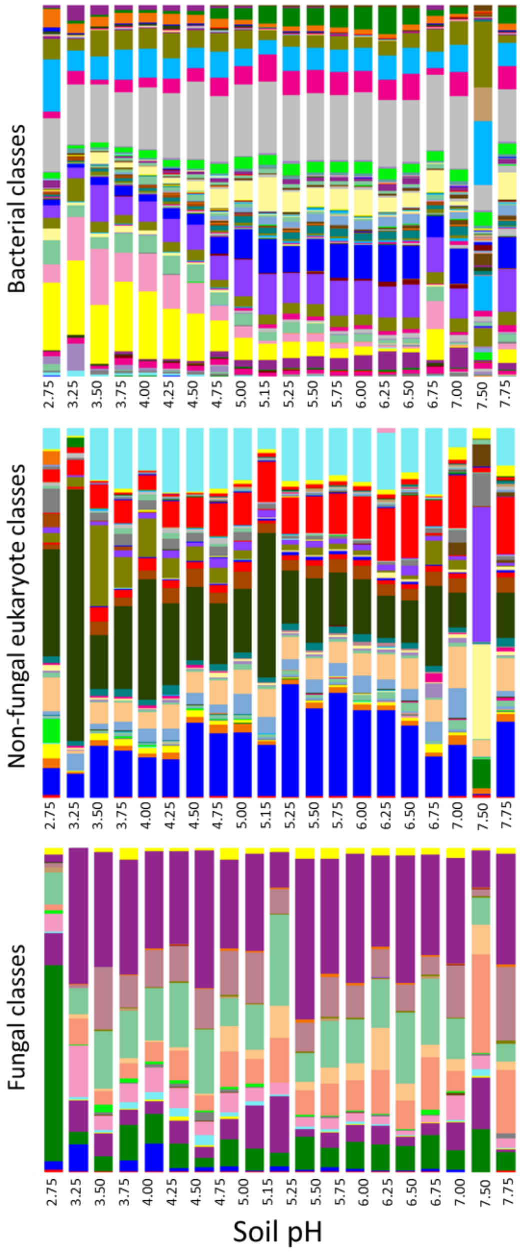


Figure 7.8.6.3.1 *The relative abundance of bacterial, non-fungal eukaryotes and fungal communities living in the soil in soil of different soil pH classes in 2013. The microbial communities are presented at the Class taxonomic level. The coloured segments in each bar represent the relative abundance of different bacterial, non-fungal eukaryotes and fungal taxonomic classes.*

The results show that pH has a major impact on the structure of soil microbial communities. This is most apparent in the bacterial community while pH trends are less apparent in the fungal and non-fungal eukaryotic communities. The results suggest that a reduction in liming, and concomitant reduction in soil pH, will induce a shift in soil microbial communities.

7.8.6.4 How does soil type influence microbial communities across the Welsh landscape?

Habitat class, soil chemical composition and soil type may all be expected to impact in topsoil microbial biodiversity. Here we explore the evidence for the influence of soil type influence.

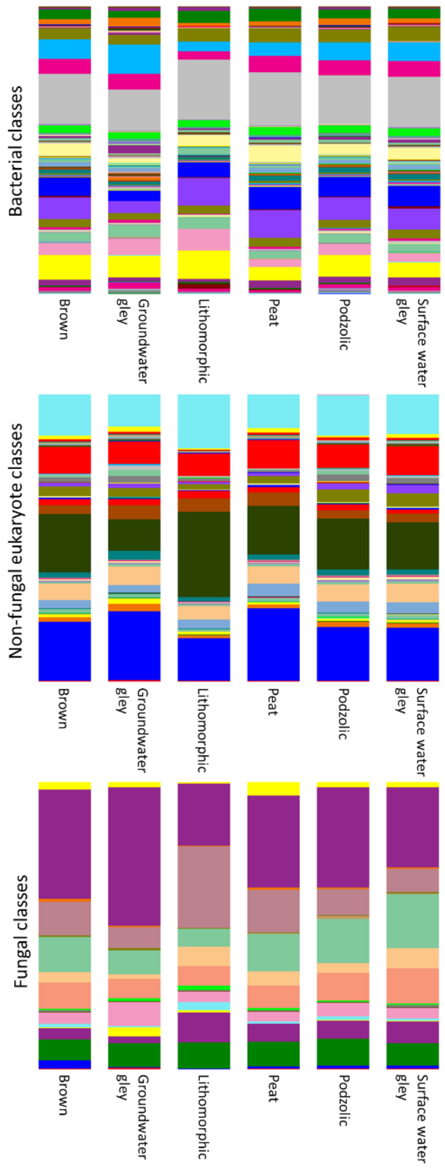


Figure 7.8.6.4.1 *The relative abundance of bacterial, non-fungal eukaryotes and fungal communities by major soil types in Wales in 2013. The microbial communities are presented at the Class taxonomic level. The coloured segments in each bar represent the relative abundance of different bacterial, non-fungal eukaryotes and fungal taxonomic classes.*

Despite the differences in the relative abundance in bacterial classes it also apparent that the same classes of microorganisms are mostly represented in all soils across Wales. The results indicate that in comparison to other factors which greatly affect soil biodiversity (e.g. Broad Habitat type), soil type has only a small influence on soil microbial communities. This suggests that it is the changes in land use under Glastir which will have a significant effect on the structure and probably functioning of the community.

7.8.6.5 Is the abundance of topsoil mesofauna changing across Wales?

Soil mesofauna (e.g. mites and collembolans) are invertebrate organisms which tend to be highly abundant and diverse in soils. Hundreds of thousands can be found in a square metre of soil. The feeding activities of these mesofauna have an important influence on a range of services provided by the soil including the breakdown of waste and organic matter, the regulation of the microbial community, nutrient cycling and pest control. In turn, the abundance and biodiversity of mesofauna can be used as an indicator of the quality or 'health' of soils.

Increasing pressures on soil biodiversity, such as land use intensification, soil organic matter decline, soil compaction and climate change, have been identified at EU level. Comparing mesofauna abundance with that recorded in previous Countryside Surveys can therefore help us establish whether soil biodiversity in Wales is increasing, decreasing or stable.

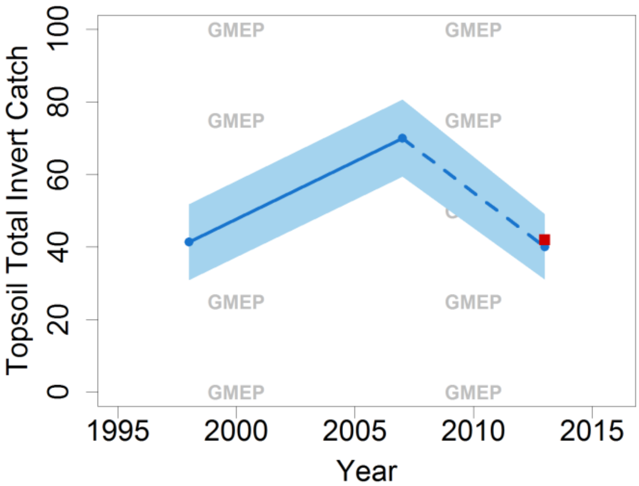


Figure 7.8.6.5.1 *Trend in topsoil mesofauna abundance using CS data (blue line); dotted line GMEP Wider Wales Survey; and re square (GMEP Targeted survey).*

The reported results are split into two groups, those representing the Wider Wales (Blue circle, 2013) part of the survey and those that represent the Targeted (Red square, 2013) part of the survey. The Wider Wales sampling is joined to the Countryside Survey long-term monitoring by the dashed line, and provides a baseline against which change can be assessed. The targeted sampling contains areas that are prioritised in Glastir for targeted options. The results presented here serve as a check to see if the samples in the targeted GMEP 1km survey squares differ from Wider Wales. The results show both samples are not significantly different. Comparing GMEP and the previous Countryside Surveys helps us to understand how soil mesofauna abundance has changed over time. This can help to establish the general status of soil quality in Wales.

The figure shows the GMEP data for soil mesofauna abundance (Total catch) in 2013 compared to data collected by the Countryside Survey in 1998 and 2007. The results show that soil mesofauna abundance in Wales has decreased since 2007 but that it is similar to data from Countryside Survey in 1998.

A healthy abundance and biodiversity of soil mesofauna is important for the breakdown of waste and organic matter, the regulation of the microbial community, and the recycling of nutrients to crops and grass. Agricultural land management which encourages a healthy soil biological community can therefore reduce requirements for external inputs e.g. fertiliser. Different groups of soil mesofauna perform varied but overlapping roles in the soil. This means that, where we can support a greater biodiversity of mesofauna, soil services will be more resilient to land management practices and environmental pressures.

7.8.6.6 How does the abundance of topsoil mesofauna vary across Broad Habitats?

While it is important to understand the overall status of soil mesofauna abundance across Wales, different habitats contain different soil biological communities. To unravel the effects of land management and environmental pressures on soil biodiversity from natural fluctuations we need to understand both the differences between these habitats and the variability within them.

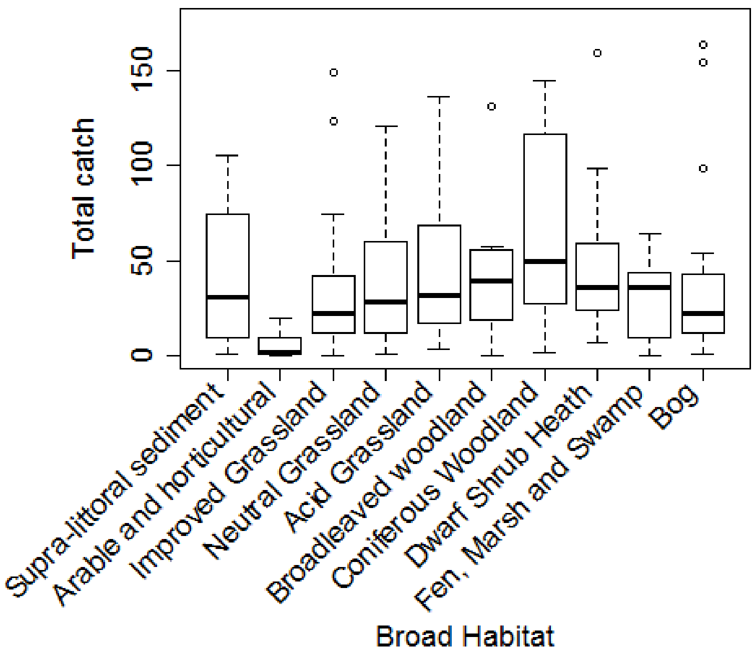


Figure 7.8.6.6.1 *Topsoil mesofauna abundance by Broad Habitats in Wales in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

Whilst there are differences between Broad Habitats they differ less than for physical and chemical characteristic which is surprising. The highest abundance of soil mesofauna are found in Broadleaved and Coniferous Woodlands, and the lowest abundance in Arable soils possibly due to inherent properties but more likely due to repeated tillage and low organic matter contents. Arable and Bog soils also have the lowest variability, while grasslands, woodlands and heath generally have much greater variability, in soil mesofauna abundance. The relative differences in soil mesofauna abundance between Broad Habitats are very similar to those reported from the Countryside Survey in 1998 and 2007, and in agreement with the wider literature.

7.8.6.7 Is there a legacy effect of past AE schemes on mesofauna?

Agri-environment schemes are expected to have a positive effect on soil mesofauna biodiversity by reducing physical disturbance and increasing soil organic matter. So that an appropriate baseline is set we want to determine if the legacy from past agricultural environment schemes e.g. Tir Gofal, Tir Cynnal, has had any detectable influence on the soil mesofauna across Wales.

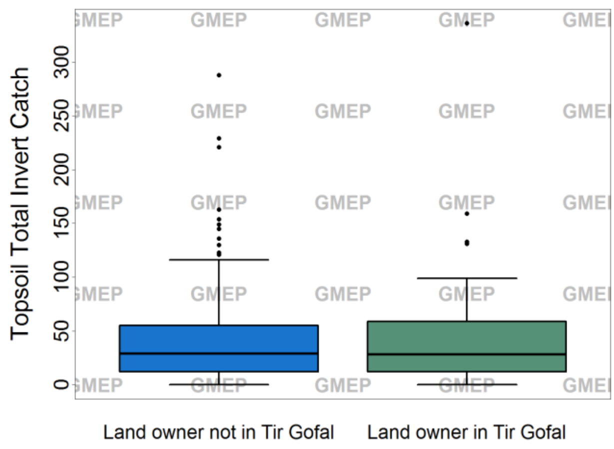


Figure 7.8.6.7.1 *Topsoil mesofauna abundance for land which was in and out of Tir Gofal using samples from 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

The figure indicates that with regard to total invert catch there was no difference between land that was in a past agri-environment scheme and land that wasn't.

7.8.6.8 Is there any difference in soil mesofauna biodiversity between soils under Glastir management compared to those out of scheme?

Setting a baseline is important, and in this first year of Glastir we want to determine if the soils selected for the Glastir scheme differ in soil mesofauna biodiversity from soils that are not selected for Glastir. In future years, this will help us to determine the impact of being in Glastir for soil quality and health.

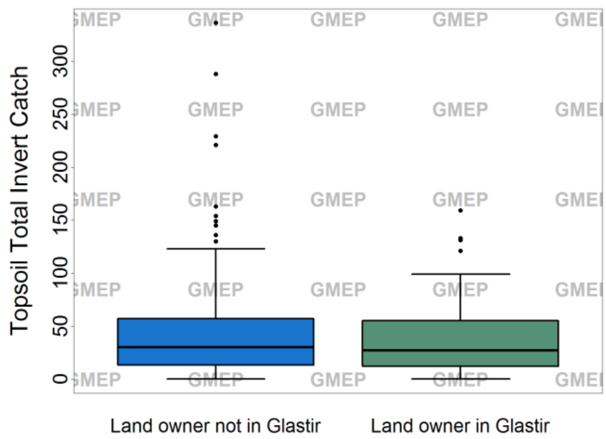


Figure 7.8.6.8.1 *Topsoil mesofauna abundance for land in and out of Glastir in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

These data indicate that there is no statistically significant difference in soil mesofauna abundance between soils being entered into Glastir, and soils outside of the scheme.

7.8.6.9 How does the biodiversity of soil mesofauna change with increasing soil organic matter?

Agri-environment schemes such as Glastir are expected to have a positive effect on soil mesofauna biodiversity. Such changes in the biodiversity may be brought about by increasing soil organic matter. While mesofauna abundance is known to increase with organic matter, it is less well understood how different groups of mesofauna respond.

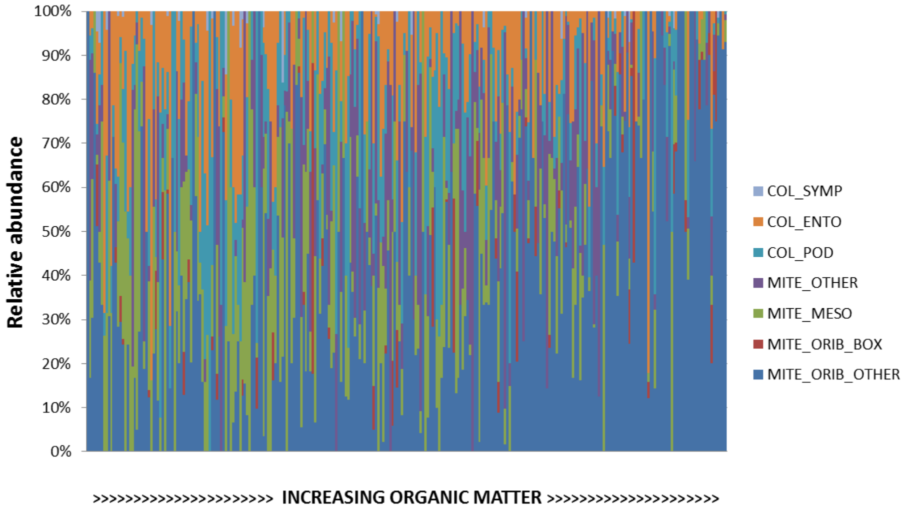


Figure 7.8.6.9.1 *Relative abundance of topsoil mesofauna by organic matter content for individual samples in 2013. These have been ordered by the associated organic matter data from these locations.*

While we can see that the different groups of soil mesofauna are found across all soils and there is much variation between samples, it is evident that their relative abundances change across the gradient of organic matter representing Welsh soils. These data can help to predict the effects of Glastir options which increase organic matter on soil biodiversity and the services to which they contribute.

7.8.6.10 Does extensification of grassland management increase mesofauna levels?

Agri-environment schemes such as Glastir are expected to have a positive effect on soil mesofauna biodiversity. Such changes in biodiversity may be brought about by increasing soil organic matter. Inputs to the soil such as mineral fertiliser can also have a negative effect on soil biodiversity. Reducing these inputs can therefore encourage greater soil biodiversity and the services to which they contribute.

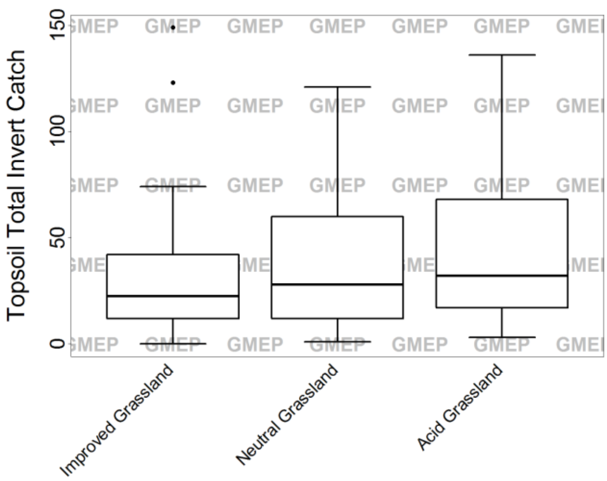


Figure 7.8.6.10.1 *Topsoil mesofauna abundance for different grassland types in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

There is not sufficient GMEP data yet on the effect of Glastir options, but differences in soil mesofauna abundance between Broad Habitats from GMEP in 2013 suggests that extensification of grassland could have a positive effect. The data show that there is a trend of increasing soil mesofauna abundance from Improved grassland to Neutral grassland to Acid grassland.

7.8.6.11 Does encouraging woody vegetation benefit mesofauna levels?

Soil mesofauna abundance and biodiversity is known to be greatest in woodland or forest systems. It is important to understand how long it would take for soil biodiversity to respond to options encouraging woody vegetation such as establishing trees or scrub.

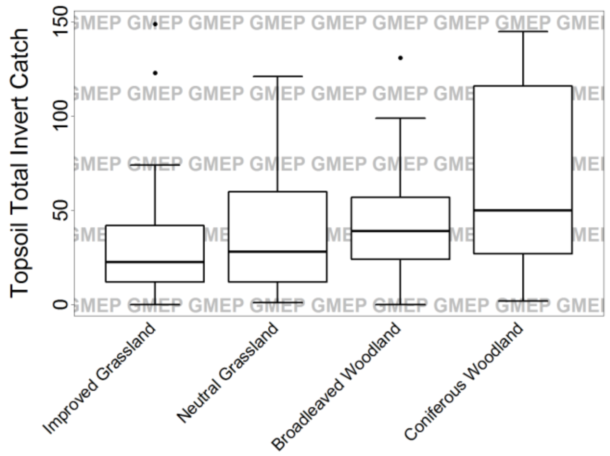


Figure 7.8.6.11.1 *Topsoil mesofauna abundance comparing grassland woodland habitats in 2013. The box indicates where 50% of the data sit with the lines showing minimum and maximum values excluding outliers which are shown by the dots.*

There is not sufficient GMEP data yet on the effect of Glastir options, but differences in soil mesofauna abundance between Broad Habitats from GMEP in 2013 suggests that encouraging woody vegetation could benefit mesofauna abundance. The data show that there is generally higher soil mesofauna abundance under Broadleaved and Coniferous Woodland compared to Improved and Neutral grassland.

7.8.7 How can we quantify the Soil Natural Capital Assets in Wales?

Soils are a fundamental resource in Wales supporting the ecosystems that in turn support agriculture and tourism. A number of initiatives are underway to recognise the value that natural resources provide to the economy. In most countries, national accounts of economic activity are recorded, and indicators such as gross domestic product (GDP) are widely used in government and policy to assess economic activity and progress. However, indicators such as GDP measure mainly market based transactions and are not good indicators of welfare; GDP ignores social costs, environmental impacts and income inequality (Costanza et al., 2014). GDP also does not deduct the direct cost of the depletion of natural resources on national income nor does it take into account the impact that our resource extraction and use of nature has on the continued functioning of the earth system for life support.

One proposal to address the deficiency of the current national accounts is to have a set of complementary accounts to augment the national accounts. Since the early 1990s, the international accounting and statistics community has been developing such a set of accounts, through the United Nations, named the system of environmental economic accounting (SEEA). The over-arching objective of the SEEA approach is to develop an accounting structure that integrates environmental information with the standard national accounts and hence mainstream environmental information in economic and development policy discussion.

The SEEA accounts are presented in two volumes. First, the SEEA Central Framework (UN et al, 2014) which was adopted as an international statistical standard in 2012, and second, the SEEA Experimental Ecosystem Accounting (UN et al., 2013). The SEEA Central Framework deals with individual environmental assets (minerals, timber, fish, water, soil, etc.), the flows of mass and energy between the environment and the economy, and the space in which this occurs. It provides a basis that can underpin accounting for soils and other natural resources in Wales.

Soils form an important part of the Central Framework, being recognized as an environmental asset in their own right. However, the detail of how to collate and present soil information and data is in its infancy. Soil resources are the volume of biologically active topsoil, and its composition in the form of nutrients, soil water and organic matter. The accounts are structured to recognize, and distinguish between, the use of an asset, e.g. soil volume and area within the asset accounts; or the use of the soil resource or elements of the soil resource e.g. carbon, nutrients and soil moisture in the physical flow accounts. Fundamental to the accounting process is the measurement of change for both the environmental and ecosystem accounts.

Using data available to GEMP we present a proof of concept approach for determining the area of soils for accounting. Using the rare and occasional soils previously identified in the HNV work, we cross analysed these with land cover data from 2007. This allows us to identify the percentage of each soil type under a particular Broad Habitat type (Table 7.8.7.1).

Analysis of land cover and soil information (Table 7.8.7.2) found that 63% of fen, marsh and swamp areas have rare soils due to the presence of peat, while 77% of saltmarsh areas contain occasional soils, predominantly of the raw gley soil type. Approximately one-fifth of urban and suburban areas also contain rare or occasional soils, along with a similar proportion for areas classified as inland rock. All of these land cover types make up a small proportion of total land cover in Wales. These landcover/soil units could then be used as the basis for area accounting. Then using historical and future landcover maps, changes in the area of soils under particular habitat types could be determined and accounted for. Hence changes in the area of soil resources could be tracked and accounted for. Decisions could then be made on whether a set of physical accounts with area changes are sufficient to inform policy, or whether economic valuation should be attempted. This preliminary work provides an important step towards the development of an internationally recognised method of accounting for soil and other natural capital in Wales.

	Broadleaved Woodland	Coniferous Woodland	Arable & Horticulture	Improved grassland	Rough grassland	Neutral grassland	Calcareous grassland	Acid grassland	Fen, marsh, swamp	Dwarf shrub heath	Heather grass	Bog	Montane habitats	Inland rock	Saltwater	Freshwater	Supra-littoral rock	Supra-littoral sed	Littoral rock	Littoral sed	Saltmarsh	Urban	Suburban
Rare Soils																							
10.2.4 Earth eutro-amorphous peat soils	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	**53.5**	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.7	0.0	0.0	0.1	0.6	0.0	0.0
10.2.2 Earthy eu-fibrous peat soils	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	**9.8**	0.1	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.3.1 Typical cambic gley soils	0.0	0.0	**0.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.5.2 Humus-ironpan stagnopodzols	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.2**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Occasional Soils																							
7.1.2 Pelo-stagnogley soils	1.1	0.2	1.2	1.1	0.4	**12.8**	0.0	0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.3	0.4	0.0	0.0	1.1	0.2	0.2	1.1	2.1
6.3.1 Humo-ferric podzols	0.5	0.5	0.1	0.2	0.8	0.0	0.0	1.9	0.0	5.1	3.0	0.1	0.0	1.0	0.0	0.2	**7.4**	0.0	2.1	0.0	0.0	0.2	0.1
5.7.2 Stagnogleyic argillic brown earths	29.1	33.5	12.1	22.2	25.4	0.7	**43.6**	24.6	0.4	16.4	24.7	1.3	4.6	12.6	10.1	10.4	9.5	0.3	1.4	1.7	0.8	7.5	9.9
3.6.1 Typical sand pararendzinas	0.5	0.9	0.2	0.2	0.6	0.0	0.0	0.0	0.2	0.4	0.1	0.0	0.0	0.7	1.8	0.5	12.6	**88.5**	2.8	36.3	3.7	4.9	1.2
9.6.2 Permeable, seasonally wet raw made ground soils	0.8	0.7	0.3	0.4	1.3	0.0	0.0	0.2	0.0	0.7	0.8	0.0	0.0	**5.6**	0.0	1.1	0.0	0.0	0.0	0.0	0.0	1.6	1.1
8.1.4 Pelo-calcareous alluvial gley soils	0.1	0.0	1.7	0.3	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	6.8	2.2	3.1	0.0	0.6	**12.2**	0.3	3.1	5.5	1.7
6.5.1 Ironpan stagnopodzols	0.0	0.4	0.0	0.0	0.3	0.0	0.0	1.0	0.0	**2.2**	2.1	0.2	0.0	1.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.5.1 Typical brown sands	2.2	0.3	3.9	2.2	0.7	26.9	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.8	**29.3**	0.0	0.0	0.1	0.1	0.4	5.6	4.8
8.1.3 Pelo-alluial gley soils	0.1	0.0	1.1	0.4	0.2	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.4	1.1	0.0	0.1	0.2	2.0	0.2	**2.4**	0.8
8.1.2 Calcareous alluvial gley soils	0.0	0.0	1.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**2.3**	1.9	0.0	0.0	0.0	1.7	**2.3**	**4.7**	0.7
3.1.3 Brown rankers	0.8	0.0	0.1	0.1	0.3	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.0	2.4	4.5	0.5	**4.9**	0.2	4.1	2.3	0.2	0.3	0.3
2.2.0 Unripened gley soils	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	2.7	0.6	0.0	1.7	0.1	20.4	**69.6**	0.0	0.1
8.2.1 Typical sandy gley soils	0.1	0.0	0.1	0.2	0.5	0.1	0.0	0.0	**11.8**	0.0	0.1	0.0	0.0	0.0	0.7	0.7	6.1	0.7	1.4	2.0	0.9	0.4	0.3
5.4.3 Gleyic brown earths	0.2	0.1	0.9	0.4	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	1.0	3.4	0.2	2.2	0.0	**5.0**	0.0	0.0	0.5	0.9
4.3.1 Typical argillic pelosols	0.3	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.8	0.0	0.0	0.2	**0.9**
8.7.1 Typical humic gley soils	0.0	0.2	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.3	**0.6**	0.0	0.0	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0
5.4.2 Stagnogley brown earths	**0.2**	0.1	0.1	**0.2**	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
9.2.4 Well aerated raw made ground soils'	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.0	**10.6**	1.3	1.8	0.0	0.0	0.0	0.1	0.0	0.7	0.1

Table 7.8.7.1 *Rare and occasional soils as a percentage of land cover type. Maximum amounts for each soil highlighted.*

	Broadleaved Woodland	Coniferous Woodland	Arable & Horticulture	Improved grassland	Rough grassland	Neutral grassland	Calcareous grassland	Acid grassland	Fen, marsh, swamp	Dwarf shrub heath	Heather grass	Bog	Montane habitats	Inland rock	Saltwater	Freshwater	Supra-littoral rock	Supra-littoral sed	Littoral rock	Littoral sed	Saltmarsh	Urban	Suburban
Rare soils																							
10.2.4 Earth eutro-amorphous peat soils	0.11	0.01	0.08	**0.45**	0.05	0.00	0.00	0.00	0.19	0.01	0.06	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01
10.2.2 Earthy eu-fibrous peat soils	0.07	0.15	0.03	0.05	0.00	0.00	0.00	0.00	0.09	0.04	0.03	**0.53**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
8.3.1 Typical cambic gley soils	0.00	0.00	**0.60**	0.38	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
6.5.2 Humus-ironpan stagnopodzols	0.19	0.04	0.01	0.06	0.01	0.00	0.00	0.14	0.00	**0.45**	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Occasional soils																							
7.1.2 Pelo-stagnogley soils	0.08	0.02	0.12	**0.55**	0.05	0.06	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09
6.3.1 Humo-ferric podzols	0.04	0.05	0.01	0.10	0.12	0.00	0.00	**0.37**	0.00	0.15	0.14	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
5.7.2 Stagnogleyic argillic brown earths	0.08	0.11	0.05	**0.41**	0.12	0.00	0.00	0.15	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
3.6.1 Typical sand pararendzinas	0.05	0.10	0.02	0.12	0.09	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	**0.39**	0.00	0.05	0.01	0.06	0.06
9.6.2 Permeable, seasonally wet raw made ground soils	0.08	0.09	0.05	**0.28**	0.24	0.00	0.00	0.05	0.00	0.03	0.05	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07
8.1.4 Pelo-calcareous alluvial gley soils	0.01	0.00	**0.30**	0.27	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.09	0.12
6.5.1 Ironpan stagnopodzols	0.01	0.09	0.00	0.01	0.11	0.00	0.00	**0.42**	0.00	0.14	0.20	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.5.1 Typical brown sands	0.07	0.01	0.18	**0.49**	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00 0	0.00	0.00	0.00	0.00	0.02	0.09
8.1.3 Pelo-alluial gley soils	0.02	0.00	0.29	**0.45**	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.06	0.08
8.1.2 Calcareous alluvial gley soils	0.01	0.00	**0.39**	0.21	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0. 0	0.00	0.00	0.01	0.02	0.15	0.10
3.1.3 Brown rankers	**0.25**	0.01	0.06	0.20	0.17	0.00	0.00	0.09	0.00	0.01	0.03	0.00	0.00	0.05	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.06
2.2.0 Unripened gley soils	0.01	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.09	**0.69**	0.00	0.01
8.2.1 Typical sandy gley soils	0.04	0.01	0.04	**0.47**	0.28	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.05
5.4.3 Gleyic brown earths	0.04	0.01	0.23	**0.47**	0.11	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10
4.3.1 Typical argillic pelosols	0.12	0.01	0.23	**0.30**	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.26
8.7.1 Typical humic gley soils	0.02	0.13	0.00	0.01	0.25	0.00	0.00	**0.32**	0.00	0.06	0.16	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.4.2 Stagnogley brown earths	0.11	0.05	0.07	**0.62**	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
9.2.4 Well aerated raw made ground soils'	0.05	0.05	0.01	0.02	0.14	0.00	0.00	0.05	0.00	0.04	0.09	0.00	0.00	**0.42**	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.05

Table 7.8.7.2 *Proportion of rare and occasional soils under each land cover type. Maximum amounts for each soil highlighted.*

7.9 Future Plans

GMEP is producing large quantities of data that will need to be analysed to synthesize the information. Bangor University and CEH have together won two prestigious PhD scholarships from NERC for students to work on data analysis. The students will start in September 2015 and work on the linkages between soil properties, soil biodiversity and above ground biodiversity.